frontiers | Frontiers in Education

ORIGINAL RESEARCH
published: 06 June 2022
doi: 10.3389/feduc.2022.875254

Support Strategy for Executive Function in Children of Low-Income Families: The Marshmallow Test Has a Learning Value

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Executive function (EF) development is an important part of infancy and childhood, promoting success in later life. Developing targeted methods is desirable to enable EF. There is an urgent need for easily implementable proposals to ameliorate educational disparities between income groups. EF is a skill that its possessor can use to inhibit thoughts and emotions. There is a relationship between EF and the prefrontal cortex. The Wechsler Intelligence Scale for Children's (WISC-IV) Working Memory Index (WMI) task for thinking and the marshmallow test for emotions have been used to measure EF, but these tests themselves carry a load of inhibitions. Therefore, we can assume a natural value in learning to improve on the test. The marshmallow test does not require parental expertise in preparation or implementation, and it entails little financial burden. If there is a potential value in learning how to do better on the test, it will be easy for parents in low-income families to help their children improve. I examined whether the marshmallow test itself can support EF. Measurements of brain activity in the prefrontal cortex over 8 days showed that the marshmallow test was more active than the WMI task or the abacus task. Therefore, the results suggest that continued use of the marshmallow test can support EF even in low-income families.

Keywords: executive function, prefrontal cortex, low-income, marshmallow test, fNIRS

OPEN ACCESS

Edited by:
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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Education

Received: *14 February 2022*
Accepted: *04 April 2022*
Published: *06 June 2022*

Citation:
Watanabe N (2022) Support Strategy for Executive Function in Children of Low-Income Families: The Marshmallow Test Has a Learning Value. Front. Educ. 7:875254. doi: 10.3389/feduc.2022.875254

INTRODUCTION

Executive Function and Family Support in Childhood

The development of executive function (EF) in childhood has become increasingly understood as important for the future success of children (Casey et al., 2011; Moffitt et al., 2011; Moriguchi, 2019). However, it is difficult to know how its development can be supported (Moriguchi, 2021). It is more difficult for children in low-income families to develop EF (Evans and Schamberg, 2009; Tough, 2012). Therefore, it is desirable to identify easier means of supporting their EF development. EF is a necessary socio-emotional skill for goal attainment and can be described as the skill of suppressing one's thoughts and emotions (Moriguchi, 2021).

The marshmallow test is often used to test the emotional suppression function of EF (Mischel et al., 1989). Similarly, the Wechsler Intelligence Scale for Children's (WISC-IV) Working Memory

Index (WMI) task has been used for thought suppression, and the abacus task is possible (Watanabe, 2021). Recent studies showed that EF is related to the activity of the prefrontal cortex through the measurement of brain activity (Moriguchi and Hiraki, 2013).

The marshmallow test is rooted in a psychological experiment on children's perseverance developed by Mischel et al. (1989). The experiment results have been used to predict children's future success (Mischel et al., 1988; Shoda et al., 1990; Michaelson and Munakata, 2020). The test activates the prefrontal cortex (Mischel, 2014), which is consistent with the observation that EF is activated in the prefrontal cortex (Moriguchi and Hiraki, 2011).

Various ways of supporting EF have been explored, but we remain in the dark overall (Moriguchi, 2021). Although much attention has been paid to the results of the marshmallow test itself, there is surprisingly little focus on the learning value of the marshmallow test. Because its design forces children to persevere, running the test itself should have a learning value. If the marshmallow test has a supportive value for EF, it can be used to support EF. In addition, the marshmallow test itself can be easily administered at home, making it usable by and for low-income families.

This study demonstrates the validity of the hypothesis that the marshmallow test itself has value for supporting EFs.

The validity of this hypothesis is determined by comparing brain activity in the prefrontal cortex. Specifically, I examine this hypothesis by comparing it with other tests of EF, such as the WMI (forward digit span and mathematics) task and the abacus task.

This study employed the case study method, useful for deriving new hypotheses (George and Bennett, 2005). Further, it has already been suggested that case studies are sufficiently valuable (Saito, 2013; Yin, 2018).

MATERIALS AND METHODS

Subjects

This single case study included one 10-year-old girl (in the fourth grade) who had passed the marshmallow test.

Ethics

The procedures involving human participants were reviewed and approved by Kwansei Gakuin University Committee for Regulations for Behavioral Research with Human Participants (Approval Number: 2020-06; Approval Date: June 12, 2020). The participants' legal guardian or next of kin provided written informed consent to participate in this study.

Methods

Prefrontal cortex activity was measured during each task [the marshmallow test, WISC-IV WMI (forward digit span and mathematics) task, and abacus task].

Brain Activity Measurement

Each task was performed eight times, once each day for 1 week and once more after 1 day's rest. Brain activity was measured during task performance. Data were omitted in cases of clearly abnormal results or where data collection was impossible. A relaxation period was provided wherein one participant sat in a chair with the brain activity device attached for several minutes or more before the task activity began. The rest period was defined as a time when the total hemoglobin (Hb) of the left and right hemispheres was less than 0.1 mMol $\times$ mm for 10 s. If there was no rest period, the measurement was deleted from the data. A two-channel fNIRS instrument took the measurements. Total Hb in mMol $\times$ mm was measured for the left and right sides.

Task/Protocol

WISC-IV WMI (Forward Digit Span, Mathematics) Task

This task was performed according to the procedure described in the general manual by Wechsler (2010). The forward digit span task was performed first, and the mathematics task second. The tasks were completed when the cancel condition was met, which entailed varying execution times for the tasks. The contents of each task are given below.

Forward Digit Span Task

In this task, the experimenter reads out a series of numbers to the subject who repeats then the numbers verbatim in the given order. There are eight questions in total; each question is further divided into two sub-questions, each of which comprises two sequences of equal length. Each sequence comprises 2–9 numbers, beginning with two-digit numbers and increasing by one digit for each number. If both sub-questions are answered incorrectly, the task is aborted.

Mathematics Task

The experimenter reads an arithmetic question to the subject in this task. There are 34 questions, and if the subject answers four consecutive questions incorrectly, the task is terminated.

Abacus Task

This activity used question sheets from the Japan Chamber of Commerce and Industry's Level 5 addition and subtraction materials. There was a 5-min time limit for each task, and the task contents were as follows.

One question comprises 10 sets of four-digit integer values (mixed addition and subtraction).

Marshmallow Test

This test was conducted using the common marshmallow test method. A time limit of 15 min is set. A desk and a chair are in a room. A marshmallow is placed on a plate on the desk, and a bell is placed on the table. The subject sits in the chair. The experimenter says, "If you can wait for 15 min, you will get another marshmallow. If you cannot wait, you will not get another marshmallow. If you can't wait, you can ring the bell. If you do, I will come back, but you will not get another marshmallow. Do not leave your chair." If the subject understood, the experimenter left the room and began the experiment.

Calculation

fNIRS was used to measure brain activity in the prefrontal cortex for each task in the subject girl. The mean value for each task was calculated. The Wilcoxon signed-rank test was used to test for significant differences. These values were calculated using IBM SPSS Statistics ver. 27.0.1.0.

Cerebral blood flow in the prefrontal cortex was measured using the HOT-2000, a two-channel fNIRS device manufactured in Japan (price: 198,000 yen), which is a wearable device and can be used outside the laboratory and at home.

The HOT-2000 takes measurements as follows. Changes in blood flow associated with brain activity are monitored using near-infrared light. Blood flow increases where the brain is most active. The measurement is performed by implanting two sensor blocks in the brain's target area of the prefrontal cortex. To obtain the measurement results, I first set the baseline correction to 0 and examined the average brain activity during the task $\{[\Sigma(f(x) - \min f(x))/\text{total milliseconds}],\ x\text{: time},\ f(x)\text{: total hemoglobin}\}$. Total hemoglobin was acquired every millisecond.

RESULTS

This was a case study of a single child, which included a within-individual comparison based on repeated experimental data.

Figure 1 and **Table 1** show the mean values for the marshmallow test, forward digit span task, math task, and abacus task. Note that for comparison with the abacus task, the marshmallow test was divided into three periods (first, second, and third section) of 5 min each.

The mean values for the left-side brain activity were in an ascending order of forward digit span task, math task, abacus task, and marshmallow test, whereas that of the right-side brain activity were in an ascending order of forward digit span task, abacus task, math task, and marshmallow test.

Table 2 shows the results of the Wilcoxon signed-rank test significant differences between left and right brain activity for each task.

The first section of the marshmallow test was significantly different in left-side brain activity from the results for the forward digit span task, mathematics task, and abacus task, while the second and third sections of the marshmallow test results were significantly different from those for the forward digit span task and mathematics task. On the right side of the brain, the results from the first and third sections of the marshmallow test were significantly different from those for the forward digit span task, mathematics task, and abacus task, while the results for the second section was significantly different from those for the forward digit span task and abacus task.

These results indicate that the marshmallow test activates the prefrontal cortex on the right, left, or both more than other approaches. This occurs even though it is performed almost every day.

DISCUSSION

The Value of Learning the Marshmallow Test

I examined whether the marshmallow test itself has any learning value. To recall, the marshmallow test is a test to determine whether a child can persevere over a short period in the hope of a reward (Mischel et al., 1989). Thus, this test places a burden of patience on its participants, although not beyond the scope needed for a psychological experiment. The tests were not conducted consecutively to avoid an undue burden. The present results, obtained through 1 week of study, indicate that the prefrontal cortex was significantly activated during the test even in children whose cortex was previously cleared of major activity. Brain activity stabilizes or declines as understanding deepens (Watanabe, 2008). The abacus produces significant activation (Watanabe, 2021). It should be noted that brain activity is more active than abacus activity. In the

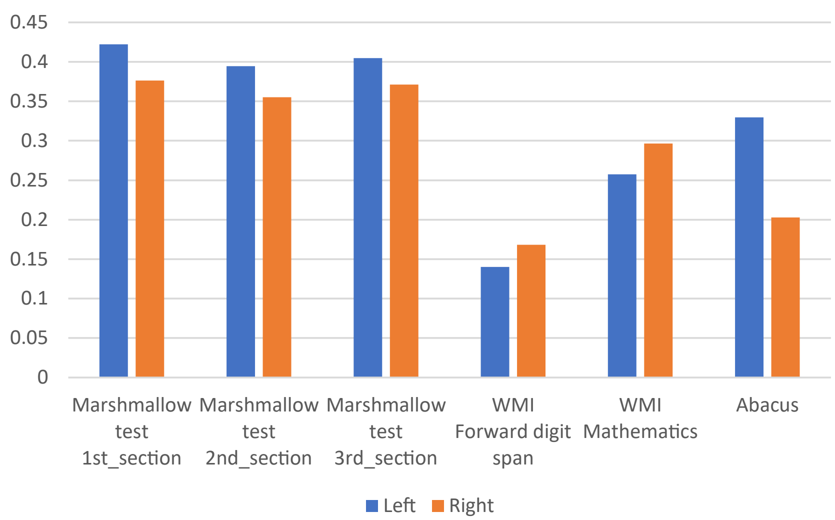

FIGURE 1 | Averages for marshmallow test, forward digit span task, math task, and abacus task.

TABLE 1 | Averages for marshmallow test, forward digit span task, math task, and abacus task.

	Marshmallow test					
	First section	**Second section**	**Third section**	**Forward digit span**	**Mathematics**	**Abacus**
Left	0.42	0.39	0.40	0.14	0.26	0.33
Right	0.38	0.36	0.37	0.17	0.30	0.20

TABLE 2 | The *p*-values for each task of the Wilcoxon signed-rank test.

	Marshmallow test				
	Second section	**Third section**	**Forward digit span**	**Mathematics**	**Abacus**
Left					
Marshmallow test (First section)	0.374	0.678	0.008**	0.025*	0.051†
Marshmallow test (Second section)		0.953	0.011*	0.036*	0.594
Marshmallow test (Third section)			0.008**	0.017*	0.11
Forward digit span				0.017*	0.021*
Mathematics					0.575
Right					
Marshmallow test (First section)	0.678	0.678	0.008**	0.093†	0.008**
Marshmallow test (Second section)		0.859	0.011*	0.484	0.028*
Marshmallow test (Third section)			0.008**	0.093†	0.008**
Forward digit span				0.017*	0.139
Mathematics					0.012*

†$p < 0.1$, *$p < 0.05$, **$p < 0.01$.

marshmallow test, they are just waiting with optimism, but they are not exactly doing anything. Additionally, this time around, a child who had already passed the marshmallow test was targeted. Therefore, the activity in the brain should be important. Experimental results reveal that "just being patient with hope" is more active than specific activities, such as the abacus task or WMI task. This perspective is groundbreaking.

EF is low in children of low-income families (Evans and Schamberg, 2009; Tough, 2012). Attachment is an important condition for support (Cicchetti and Blender, 2006; Dozier et al., 2006; Gunnar and Fisher, 2006). In addition, it is difficult for low-income families to provide advanced knowledge to their children or find the funding or time to instruct them. The marshmallow test requires only two marshmallows, a clock, a room, a desk, a chair, a plate, and a bell. Further, the test administrator need not monitor the child for the full 15 min, and in the end, praise is all that is needed. The object need not be marshmallows but cookies, stickers, or any number of other things. There are many test variations, which can easily be done every day. Low-income families often do not know how to support EF in their children or have insufficient resources, even when they are aware. Even for low-income families, the marshmallow test may be an easy first step.

This time the child is one who passed the marshmallow test. That is, she is a child who was able to endure for 15 min; however, if one cannot stand it for 15 min, I do not think it will be a problem. This is because family support thus requires only a little parental and autonomous support for the child (Bernier et al., 2010). Children adapt to their environments (Moriguchi, 2021). Experiments have shown that reliable experimenters can wait three times longer than trustworthy ones (Michaelson and Munakata, 2016). The suggestion of a casual implementation of the marshmallow test provides effective autonomy support for parents and children.

It is less important whether a child completes the marshmallow test, but it is hoped that by continuously conducting the marshmallow test, a relationship of trust between parents and children can be established. Using this as advantage, EF can gradually be fostered by learning patience during the marshmallow test.

Although the present study was conducted on a single subject to show the activation of brain activity, it is a significant first step to show the value of implementing the marshmallow test in EF development.

Limitations

This study had some limitations. Only one child was included in the study. Larger populations should be tested in the future. Moreover, showing the superiority of the test compared to other tests is necessary.

The 2-channel fNIRS device has the advantage of being easily measurable. However, only the overall measurement of the prefrontal cortex is possible. Therefore, it is difficult to clarify the detailed relationship between EF and marshmallow test and other tasks; thus, using a multi-channel fNIRS device, such as one with 10 or 16 channels, for measurement and examining them in more detail is necessary.

Ripple Effects

This study is expected to impact research fields related to family support for FE significantly. It will also be valuable in providing new perspectives on educational psychology, cognitive psychology, and neuropsychology.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available owing to privacy and ethical restrictions. Requests to access the datasets should be directed to NW, nobuki@kwansei.ac.jp.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Kwansei Gakuin University Committee for Regulations for Behavioral Research with Human Participants. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

The author made substantial contributions to the conception or design of the work or the acquisition, analysis, or interpretation of data for the work.

FUNDING

This work was supported by JSPS KAKENHI under Grant Number 22K02535.

ACKNOWLEDGMENTS

The author would like to thank Enago (http://www.enago.jp/) for the English language review.

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Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.